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Families among the Hildas and Trojans

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Abstract. A search for asteroid families among the Hildas and Jupiter Trojans was performed with the use of a new set of proper elements. The proper elements were calculated by the empirical method. Besides well known families, several new probable families were found in addition.

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1. The Hildas and Trojans resonant regions

A search for asteroid families among the Hildas and Trojans by analytical methods is especially difficult because these asteroids move in resonance regions. The Hildas are in the 3:2 and Trojans in the 1:1 mean motion orbital resonances with Jupiter. To find asteroid families, proper elements should be calculated. A concept of proper elements has been introduced by Hirayama (Hirayama 1918). There are different methods of proper elements calculation: analytical, numerical, and empirical which uses distributions of orbital elements.

2. Hirayama (1918) work

What method did Hirayama use? Hirayama selected some condensations in distributions of osculating elements. For each of the selected groups he studied its distribution in the $(\tan i \cos \Omega, \tan i \sin \Omega)$ and $(e \cos \varpi, e \sin \varpi)$ planes. Here i is inclination, Ω - longitude of ascending node, e - eccentricity, ϖ - longitude of perihelion. Hirayama noticed that these distributions have the form of a circle. For each of selected group he found visually the position of a center of a circle. This point corresponds to forced elements. A distance of a dot from the center is a proper element (i_p or e_p). Also he applied the secular theory and defined that such distribution is due to secular perturbations by Jupiter. So, Hirayama used two methods: first empirical, then analytical.

3. The Empirical method

After Hirayama's work the empirical method was not used. The new empirical method described in (Vinogradova (2015)) allows us to calculate forced elements. If forced elements are known, proper ones can be calculated with the use of a coordinate transformation formula. The method is simple and not time-consuming. It allows us to use all available asteroids for a family identification. The MPC catalogue, version May. 2018, was used as a source of initial osculating elements.

4. Asteroid families in the Hilda-group

The number of multi-opposition Hildas now exceeds 3000. Two forced elements derived for the Hildas, $i_f = 1.20^o \pm 0.05^o$ and $\Omega_f = 99^o \pm 1^o$, are in a good agreement with results of the secular theory (Brouwer & van Woerkom (1950)), but two other elements, $e_f = 0.069 \pm 0.002$ and $\varpi_f = 20^o \pm 2^o$, differ significantly from these results (0.043 and 12^o, respectively). One of the features of the motion in these resonant regions is the libration of the semimajor axis. It was accepted to use a value $a_p = 3.97au + da$ as a proper semimajor

Table 1. Families among the Hildas and Jupiter Trojans.

Region	Name	FIN	Diam (km)	N	d_{cut} 10^{-4}	Tax	p_v	Δa_p (au)	Δe_p	Δi_p (deg)
Hilda-group	1911 Schubart	002	80+66	658	30-110	CX-7:1(36)	0.04	3.98-4.04	0.15-0.23	2.6- 3.2
	153 Hilda	001	167+100	433	90-200	CX-6:2(59)	0.06	3.98-4.03	0.11-0.25	7.8-10.4
	1212 Francette	-	83+ 21	42	110-210	P -(1)	0.06	3.98-4.01	0.22-0.24	6.9- 7.6
	51874 2001 PZ28	-	13+ 28	52	130-250	DS-8:1(6)	-	3.98-4.02	0.20-0.25	10.3-11.8
	2483 Guinevere	-	43+ 38	81	140-230	DC-5:2(4)	0.07	3.98-4.03	0.20-0.27	4.7-6.3
	4757 Liselotte	-	18+ 24	17	180-230	-	-	3.99-4.02	0.14-0.16	1.1-1.8
	5661 Hildebrand	-	38+ 28	29	220-370	-	-	3.98-4.01	0.19-0.23	13.7-15.0
L4-Trojans	3548 Eurybates	005	66+ 80	317	50-120	CX-5:4(10)	0.06	5.28-5.33	0.03-0.07	7.1- 7.8
	2148 Epeios	008	39+ 55	104	100-160	-	-	5.23-5.33	0.02-0.05	8.6-9.2
	624 Hektor	004	207+121	100	110-290	DL-9:1(11)	0.05	5.23-5.35	0.03-0.09	17.8-19.4
	9799 1996 RJ	006	65+ 30	19	140-390	-	0.04	5.23-5.24	0.03-0.05	31.4-31.8
	9713 Oceax	-	31+ 66	122	160-210	DX-5:5(2)	-	5.25-5.38	0.02-0.05	3.4-5.0
	2797 Teucer	-	112+113	41	160-280	D (2)	0.07	5.23-5.32	0.06-0.08	20.3-21.5
	1583 Antilochus	-	117+ 79	41	260-490	D (2)	0.09	5.23-5.33	0.01-0.08	28.3-29.5
L5-Trojans	1172 Aneas	-	137+109	55	190-300	DC-7:1(9)	0.05	5.22-5.33	0.03-0.06	16.6-18.8
	1867 Deiphobus	009	128+ 91	139	200-270	DC-7:1(6)	0.06	5.23-5.34	0.02-0.05	26.8-31.2
	11487 1988 RG10	-	28+ 48	37	210-270	DX-7:1(7)	-	5.24-5.37	0.02-0.04	3.8-4.8
	37519 Amphios	010	35+ 27	14	210-270	-	-	5.22-5.23	0.04-0.05	24.4-25.1

Notes: Diam - diameter of the main asteroid + diameter of debris; N - number of members; d_{cut} - dimensionless d_{cut}-distance; Tax - shares of taxonomical types and a number of members with known taxonomy (in brackets); p_v - albedo; Δa_p, Δe_p, Δi_p - intervals of proper elements.

axis for the Hildas (da is the libration amplitude). We adopt an approach similar to the hierarchical clustering method for identification of asteroid families. As a result, two large families were found here: (1911) Schubart and (153) Hilda. Both these families were found earlier by other authors (Schubart (1982)), (Brož & Vokrouhlický (2008)). In Asteroids IV these families were assigned FIN - family identification number (Nesvorný, Brož, Carruba (2015)). In addition, our new set of proper elements enables five probable families to be identified (see Tab.1).

5. Asteroid families in the Trojans

About 5000 multi-opposition asteroids are known in the Trojans now (3300 in L4 + 1700 in L5). Calculating the proper elements of the Trojans is easy, because orbital elements of Jupiter can be used as forced elements: $i_f = 1.3^o$, $\Omega_f = 100.5^o$, $e_f = 0.049$, $\varpi_{jup} = 14.2^o$. For L4-Trojans, $\varpi_f = \varpi_{jup} + 60^o = 74.2^o$. For L5-Trojans, $\varpi_f = \varpi_{jup} - 60^o = 314.2^o$. A proper semimajor axis $a_p = 5.20 + da$, where da is a libration amplitude. Large discrepancies take place in the Trojans family lists obtained by different authors. The number of families found differs from one (Brož & Rozehnal 2011) to about 20 (Beaugé & Roig 2001). With our new set of proper elements seven families were found among the L4-Trojans and four among the L5-Trojans. All additional families among the Trojans were previously found by different authors, but at the same time a large number of families published earlier were not confirmed.

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